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EXPERIMENTAL STUDY ON COMPARISON OF ENERGY CONSUMPTION BETWEEN CONSTANT AND VARIABLE SPEED AIR-CONDITIONERS IN TWO DIFFERENT CLIMATES

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ABSTRACT: It is well known that an inverter-driven variable speed compressor (or inverter) air-conditioner is more efficient than a constant speed compressor air-conditioner. Therefore, most countries have adopted part-load assessment test standards such as ISO 16358, EN 14825 and ASHRAE 116 in addition to the conventional ISO 5151 full-load test standard. However, many countries in the Middle East and South America still adhere to ISO 5151 standard for policy or high temperature environment reasons. In this study, we experimentally verify the energy saving effect of an inverter air-conditioner compared to a constant speed air-conditioner in the Korean climate with distinct temperature changes across four seasons and in the perpetually hot climate of Saudi Arabia. From extensive regional and seasonal climate data in Saudi Arabia and South Korea, changes in temperature conditions are applied directly to the outdoor side, and TRNSYS simulated heat flux conditions to the indoor side of an air-enthalpy type test room. Results show that the energy reduction effects of using an inverter air-conditioner are largely dependent on the temperature and cooling load changes for a day or a season.

Keywords: Constant/Variable speed, Inverter air-conditioner, Energy saving, Korean climate, Saudi Arabian climate

1. INTRODUCTION

The energy efficiency of an air-conditioner is largely described in two ways, one is EER by ISO 5151 [1], and the other is Seasonal EER (SEER) by ISO 16358 [2], EN 14825 [3] and ASHRAE 116 [4]. Despite the improvement of air-conditioner technology by developing an inverter-driven variable speed compressor (simply, 'inverter'), some countries in the Middle East and South America still prefer to use full-load evaluation methods because the ISO 5151 full-load test is simple, and the hot climate of much of the season needs the full operation of an air-conditioner. However, there are winter periods in regions of the Middle East that do not require air-conditioning, and months exist in which a part-load operation is required before and after the peak of summer.

Two prior studies exist that compared the performance differences between constant speed and variable speed air-conditioners. One was conducted on a specific sized real room with a start operation at a preheated temperature, and it saw the effects of the products' temperature setting and space heat load [5]. The other studied real office usage circumstances with a relatively long term power input measurement [6]. However, neither studies compared the performance differences under the controlled temperature variations and building cooling load variations in an accurately controlled test room.

In this paper, we analyze the energy saving effect of an inverter versus a constant speed air-conditioner during cooling periods in South Korea and Saudi Arabia. The analysis areas are Seoul and Riyadh, the representative capital cities. During the cooling periods (Seoul 4 months, Riyadh 9 months), building cooling loads are simulated through the TRNSYS program. Then, simulated monthly cooling load data are applied to the indoor side of an air-enthalpy type air-conditioner test room with the simultaneous application of monthly temperature data to the outdoor side. Through this new experimental approach, the energy saving effect of an inverter air-conditioner can be known.

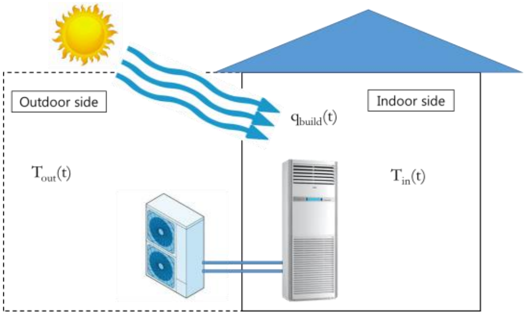

Fig. 1(a) Basic model for the analysis

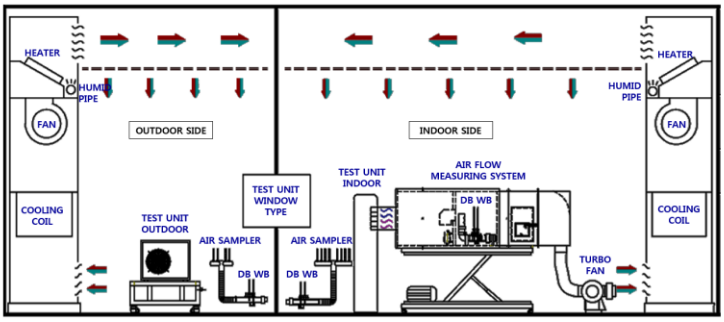

Fig. 1(b) Air-enthalpy type test room used for the experiment

2. EXPERIMENTAL APPROACH

Unlike the (T_{out}/T_{in}) environmental setting of ISO test methodology, we give the temperature in the outdoor side and the building cooling load in the indoor side (T_{out}/q_{build}). In other words, we set the temperature of the outdoor side for the simulation of heat reservoir outside, and apply the heat flux condition in the indoor side for the simulation of heat infiltration or generation. T_{out} and q_{build} are given time dependently, as in the basic model of Fig. 1(a). In order to measure the energy consumption in each case of the constant speed and variable speed air-conditioner, the temperature changes of the outdoor ($T_{out}(t)$) and the heat flux changes of the indoor ($q_{build}(t)$) are applied in the air-enthalpy test room shown in Fig. 1(b). Outdoor temperature data are secured for the capital cities of South Korea and Saudi Arabia during the cooling seasons, and the heat flux data are obtained by TRNSYS modeling.

Korea is located geographically in a mid-latitude temperate climatic zone, and the four seasons of spring, summer, fall, and winter are conspicuous. In winter (Dec.~Feb.), it is cold and dry under the influence of the continental air from northern China and Siberia. In summer (Jun.~Aug.), hot and humid weather from Pacific atmospheric pressure is reflected. In spring (Mar.~May) and autumn (Sep.~Nov.), there are many sunny days due to the influence of migratory anticyclones. The climate of Saudi Arabia is marked by high temperature during the day and low temperature during the night. Most of the country follows the pattern of a desert climate, with the exception of the southwest region, which features a semi-arid climate [7].

Table 1 shows the distribution of the monthly temperature in Seoul and Riyadh, the capital city of South Korea and Saudi Arabia, respectively. In Seoul, the cooling season is from June to September, and in Riyadh from March to November. In both cities, continuous air-conditioning is not required for all cooling periods. In Seoul, air-conditioner works intermittently during the entire cooling period. In the case of Riyadh, air-conditioning operates intermittently in March, April, September, October, and November.

Table 1. Temperatures in Seoul & Riyadh (average high, daily mean, average low)*

City	Temperature	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Seoul	High (°C)	2	5	10	18	23	27	29	30	26	20	12	4
	Mean (°C)	-2	0	6	13	18	22	25	26	21	15	7	0
	Low (°C)	-6	-3	2	8	13	18	22	22	17	10	3	-3
Riyadh	High (°C)	19	23	27	32	38	41	43	42	40	34	27	22
	Mean (°C)	14	17	21	27	32	34	36	36	33	28	22	17
	Low (°C)	11	15	21	26	28	29	27	26	20	16	11	9

* Climate data from Wikipedia ("Climate of Seoul", "Climate of Saudi Arabia"). Originally from Weather-base.

Table 2. Specifications of constant speed vs. variable speed air-conditioners

Contents	Constant speed	Variable speed
Electricity	Single phase, 230 V, 60 Hz	Single phase, 230 V, 60 Hz
Rated cooling capacity (T1 climate)	5,130 W	5,275 W
Rated power input (T1 climate)	1,520 W	1,490 W
Rated current (T1 climate)	6.8 A	6.7 A
EER (T1 climate)	3.38	3.54
Cooling capacity (T3 climate)	4,420 W	4,484 W
Power input (T3 climate)	1,820 W	1,754 W
Current (T3 climate)	8.14 A	7.8 A
EER (T3 climate)	2.43	2.56
Maximum power input	2,610 W	2,900 W
Maximum current	11.68 A	14.0 A
Refrigerant	R410a, 0.85 kg	R410a, 0.95 kg
Product type	Wall mount split type	Wall mount split type

Table 3. TRNSYS simulation conditions in Seoul & Riyadh

Input Variables	Seoul	Riyadh
Space size (single zone)	10m × 8m × 2.5m	10m × 8m × 2.5m
Window	60% of the southern wall area – 15 m^2	30% of the southern wall area – 7.5m^2
Floor of space	Located between floors – up and down insulations	Located between floors – up and down insulations
Glass	1.20 W/m^2K	1.720 W/m^2K
Wall	0.21 W/m^2K	0.345 W/m^2K
Room temperature & humidity	26°C & 60 %R.H.	26°C & 60 %R.H.
Heating & light element	25 W/m^2	25 W/m^2
Persons	4 persons	4 persons
Infiltration	0.4 (1/h)	0.4 (1/h)
Ventilation	0.6 (1/h)	0.6 (1/h)

For the comparison test of constant and variable speed air-conditioners, products of similar specifications are selected, as in Table 2. The two products have similar specifications of capacity, power input, and EER values within 5% relative differences. The purpose of this paper is to check the energy saving effect of a variable speed air-conditioner under real climate conditions when the full-load specifications are similar with the constant speed product.

The TRNSYS program (version 17) was used to acquire the building cooling load for the cooling periods. We applied several years of meteorological data of Seoul and Riyadh embedded in the TRNSYS program. TRNSYS ERC (Energy Rate Control) method was used to analyze the seasonal building cooling load. Modules of type 15-2, type 56, TRNSYS 3D Plugin, and Google SketchUp were utilized. We set up a single zone of the same size in Seoul and Riyadh, but the window size was set to suit the reality of each country. Saudi homes typically have small windows to block direct solar radiation. The properties of glass and wall material are applied by referring to Korea's architectural regulation notification [8] and a Saudi paper [9]. The room temperature setting on the TRNSYS simulation is set to 26°C, which is the same as the air-conditioner temperature setting during the experiment. Details are in Table 3.

3. RESULTS AND ANALYSIS

Before the experiments comparing constant speed and variable speed (inverter) air-conditioners, TRNSYS monthly simulation results were acquired for the building cooling loads in Seoul and Riyadh, as shown in Fig. 2(a) and Fig. 2(b). The reason for the two cities having a similar maximum building load value (about 4,000 W) is that the humidity in summer is very low in Riyadh and very high in Seoul. Figs. 3-4 show the experimental results comparing the constant speed air-conditioner and the inverter air-conditioner. Experimental data of indoor building loads and outdoor temperatures follow the TRNSYS simulation results well when considering the rectangular and circle points in each figure.

The biggest difference in the graph between the constant speed and the inverter air-conditioners is the variation of the power input. The constant speed air-conditioner represents simple on/off controlled power input, whereas the inverter (variable speed) air-conditioner's power input shows variations corresponding to the building load or outdoor temperature. Power inputs can be averaged to obtain daily average power consumption. Table 4 shows the monthly power consumption obtained by multiplying 30 (days) in the daily average power consumption. During the cooling seasons of Seoul (4 months) and Riyadh (9 months), monthly power consumptions are compared between the constant and the variable speed air-conditioners. When we consider the air-conditioner specification of Table 2, the tested variable speed air-conditioner itself has a higher EER value than the constant air-conditioner by around 5%. Therefore, the relative difference is finally subtracted by -5%, as shown in Table 4.

For the Seoul and Riyadh cases, the variable speed air-conditioner shows less energy consumption from 36.3% to 51.7% and from 18.3% to 47.1%, respectively. It shows that the variable speed air-conditioner has relatively higher energy saving effects than the constant speed air-conditioner in part-load cooling months. In total, in the case of Saudi Arabia, 28.9% inverter energy saving is achieved, and 44.5% in Korea during the cooling season. These results are very similar with the former study of Istanbul [6], which also reports 11~38% energy savings for the inverter air-conditioner in real office usage.

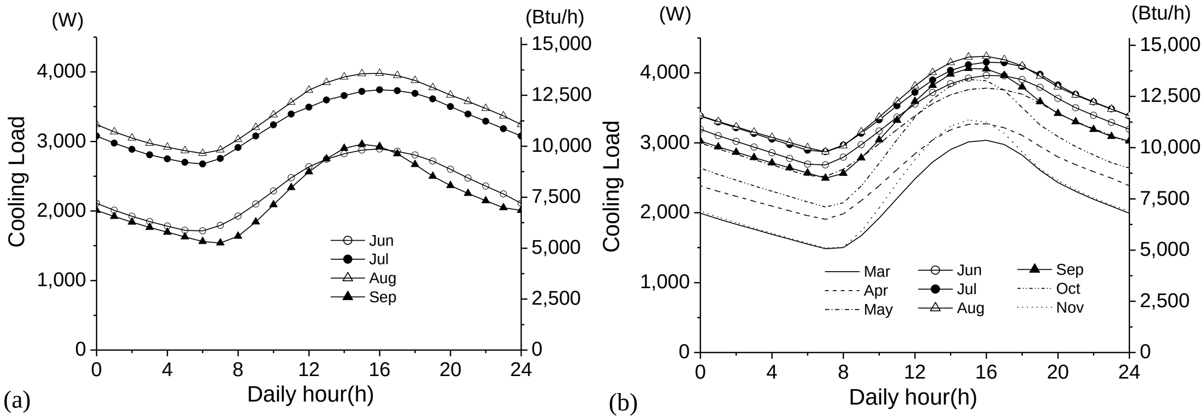

Fig. 2 Building cooling load (a) Seoul (b) Riyadh

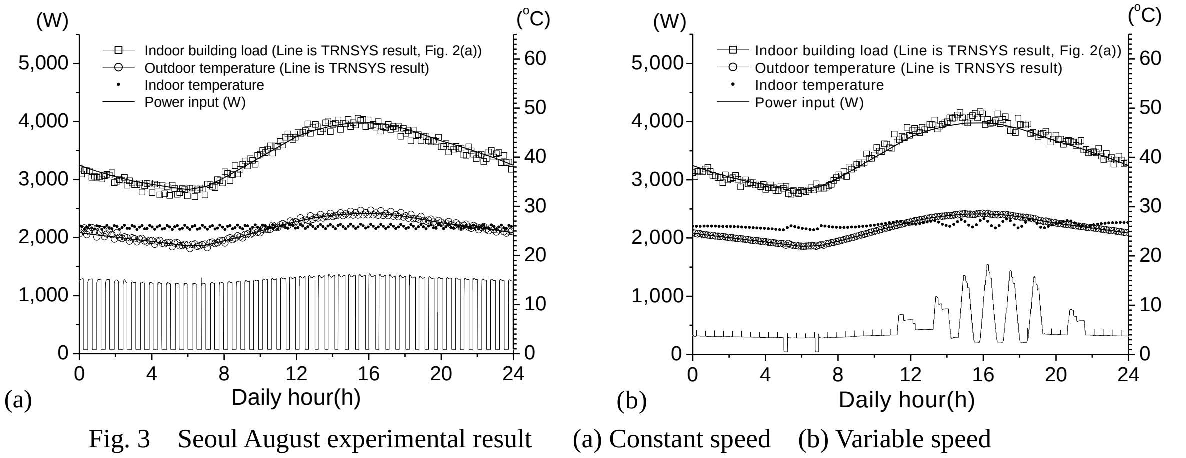

Fig. 3 Seoul August experimental result (a) Constant speed (b) Variable speed

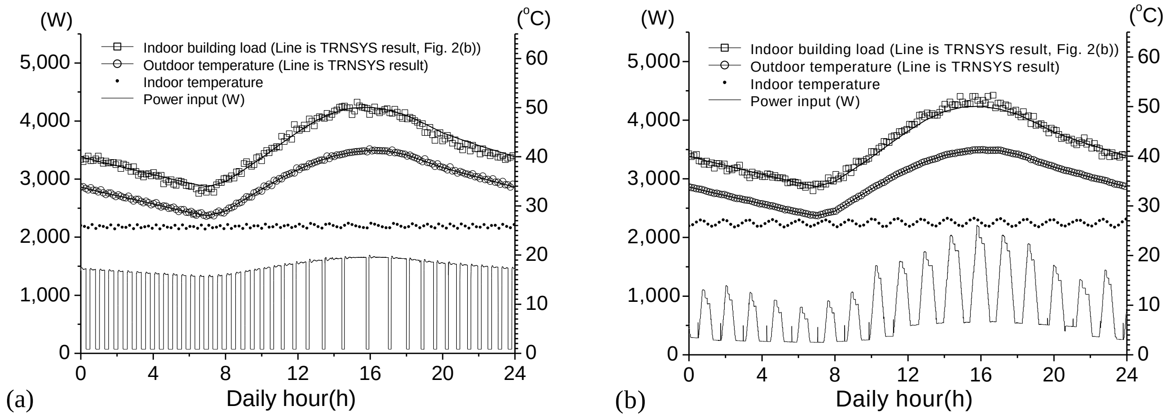

Fig. 4 Riyadh August experimental result (a) Constant speed (b) Variable speed

Table 4. Monthly power consumption (kWh) during cooling season

City	A.C. type	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Tot.
Seoul	Constant speed	-	-	-	341	490	542	319	-	-	1,692
	Variable speed	-	-	-	150	249	318	138	-	-	855
	(Con.–Var.)/Con. × 100%	-	-	-	56.0	49.2	41.3	56.7	-	-	49.5
	–5% compensation	-	-	-	**51.0**	**44.2**	**36.3**	**51.7**	-	-	**44.5**
Riyadh	Constant speed	305	421	603	672	745	747	595	470	330	4,888
	Variable speed	149	237	395	459	529	573	435	298	158	3,233
	(Con.–Var.)/Con. × 100%	51.1	43.7	34.5	31.7	28.9	23.3	26.9	36.6	52.1	33.9
	–5% compensation	**46.1**	**38.7**	**29.5**	**26.7**	**23.9**	**18.3**	**21.9**	**31.6**	**47.1**	**28.9**

4. CONCLUSION

In this study, the energy saving effect of an inverter (variable speed) air-conditioner compared to a constant speed air-conditioner across both Korean and Saudi Arabian cooling periods was directly experimented. The ambient temperature and building cooling load were obtained from TRNSYS internal climate data and simulation. These results were experimented in a precisely controlled air-enthalpy type test room (outdoor side – temperature, indoor side – heat flux controlled) with specific size and containing an air-conditioner of 26.0°C temperature setting all day. For the Korean and Saudi Arabian cooling periods, 4 and 9 months respectively, TRNSYS simulations and experiments in the air-enthalpy test room were implemented.

Results show that a variable speed (inverter) air-conditioner is more efficient than a constant speed air-conditioner, even in a hot Saudi Arabian climate. Inverter energy savings of 18.3% to 47.1% were observed during the Riyadh's cooling months (Mar. ~ Nov.) and 36.3% to 51.7% during Seoul's cooling months (Jun. ~ Sep.). Energy savings depend on the month, and relatively more energy savings are seen before and after the peak summer. A variable speed (inverter) air-conditioner is more effective than a constant speed air-conditioner particularly in the months of and in the location of part-load operation, while it shows less energy usage in all present test cases.

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